ANL/MSD/CP-108716

APT #44395

58510

Pressure-Dependent Magnetoresistance Studies of β''-$(ET)_2SF_5CH_2CF_2SO_3$*

J. Hagel[1], J. Wosnitza[1], C. Pfleiderer[2], J. A. Schlueter[3], U. Geiser[3], J. Mohtasham[4], R. W. Winter[4], and G. L. Gard[4]

[1]Institut für Angewandte Physik, D-01062 Dresden, Germany
[2]Physikalisches Institute, Universität Karlsruhe, D-76128 Karlsruhe, Germany
[3]Materials Science Division, Argonne National Laboratory, Argonne, IL 60439
[4]Department of Chemistry, Portland State University, Portland, OR 97207

Submitted for publication in

Synthetic Metals
Proceedings of the International Conference on Synthetic Metals
Shanghai, China
June 29-July 5, 2002

*Work supported by the U.S. Department of Energy, BES-Materials Sciences, under Contract W-31-109-ENG-38.

Pressure-dependent magnetoresistance studies of β''-$(ET)_2SF_5CH_2CF_2SO_3$

J. Hagel [a,*] J. Wosnitza [a], C. Pfleiderer [b], J.A. Schlueter [c], U. Geiser [c], J. Mohtasham [d], R.W. Winter [d], G.L. Gard [d]

[a] *Institut für Angewandte Physik (IAPD), TU Dresden, D-01062 Dresden, Germany*
[b] *Physikalisches Institut, Universität Karlsruhe, D-76128 Karlsruhe, Germany*
[c] *Materials Science Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*
[d] *Department of Chemistry, Portland State University, Portland, Oregon 97207, USA*

Abstract

We report on the electronic transport properties of the organic superconductor β''-$(ET)_2SF_5CH_2CF_2SO_3$ at high fields and under hydrostatic pressure. With increasing pressure the superconducting transition temperature decreases in line with a decreasing effective mass. The closed Fermi-surface (FS) area increases strongly but the FS topology remains unchanged.

Keywords: Organic superconductors, Transport measurements, magnetotransport

The electronic properties of the quasi-two-dimensional (2D) organic superconductors based on ET (= BEDT-TTF = bisethylenedithio-tetrathiafulvalene) are very sensitive to external pressure p. This is evidenced e.g. by the strongest known pressure dependence of a superconducting transition temperature, T_c, in κ-$(ET)_2Cu(NCS)_2$ ($dT_c/dp \approx -3.5$ K/kbar) [1]. The origin of this strong pressure effect in organic superconductors might be related to an increase of the electronic bandwidth resulting in a decreasing density of states at the Fermi energy or/and a change of phonon modes which might be responsible for the pairing interaction. Nevertheless, both effects cause a reduced coupling strength λ resulting in a decrease of $T_c \propto \exp(-1/\lambda)$.

For the organic superconductor β''-$(ET)_2SF_5CH_2CF_2SO_3$ with $T_c = 4.4$ K (from specific-heat, resistive onset at about 5.2 K), $dT_c/dp = -1.4$ K/kbar was found for hydrostatic pressure measured up to 2.5 kbar [1]. This is in line with thermal-expansion data yielding a similar incipient p dependence [2]. Here, we expand the pressure range up to about 14 kbar and, in addition, investigate the electronic band-structure parameters of β''-$(ET)_2SF_5CH_2CF_2SO_3$ by means of Shubnikov–de Haas (SdH) and angular-dependent magnetoresistance (AMRO) measurements.

Two single crystalline β''-$(ET)_2SF_5CH_2CF_2SO_3$ samples were investigated. Thin current leads (25 μm gold wire) were glued with graphite paste to the samples. The interplane resistance was measured by a two-point (sample A) and four-point (sample B) method inside a CuBe pressure cell by use of a low-current low-frequency ac-resistance bridge. The low-temperature pressures of up to ~14 kbar were determined with an accuracy of about 0.2

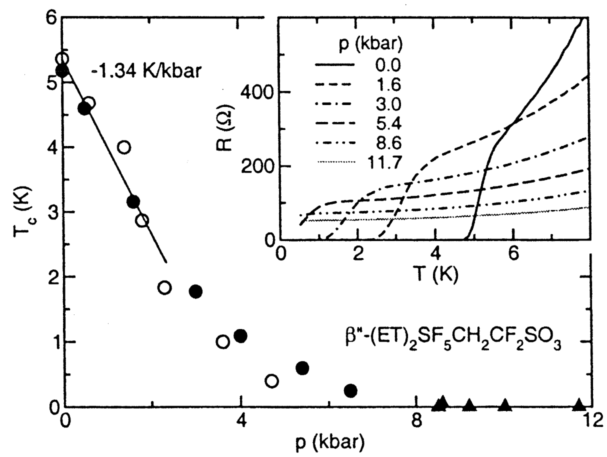

Fig. 1. Pressure dependence of T_c for two different samples. The circles represent the midpoint of the transition. The triangles indicate the resistive onset. The inset shows the resistance data of sample B close to the superconducting transition for different pressures.

*Corresponding author: FAX: +49-351-463-33199; e-mail: Hagel@physik.tu-dresden.de

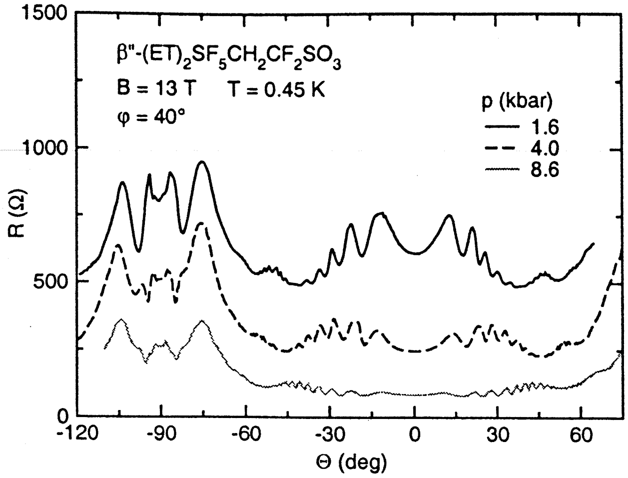

Fig. 2. Angular dependence of the magnetoresistance of sample B for three different pressures. Besides the first AMRO peak at about -75 deg mainly SdH oscillations appear.

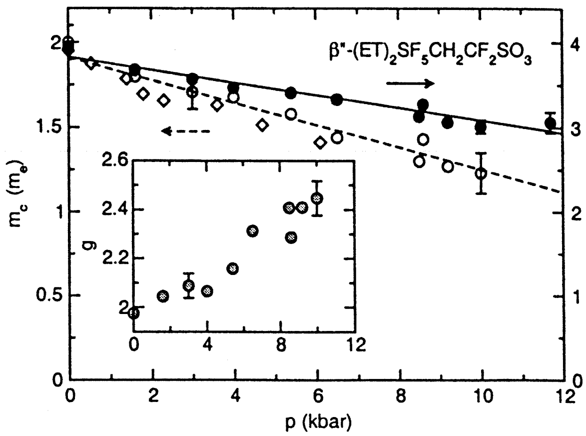

Fig. 3 Pressure dependence of the effective mass m_c (open symbols for two samples) and of gm_c (closed circles). The inset shows the pressure dependence of the g factor.

kbar by resistively measuring T_c of a Sn wire mounted next to the samples inside the pressure cell. The cell could be rotated *in situ* around two axes. Temperatures down to 0.4 K were achieved by use of a ^{3}He cryostat equipped with a superconducting 15 T magnet.

The temperature dependence of the resistance of sample B is shown in the inset of Fig. 1 for $T < 8$ K. The rapid suppression of the superconducting transition under pressure is evident. The pressure dependence of T_c for both samples is displayed in Fig. 1. At low pressures ($p < 3$ kbar) we find a linear decrease of T_c with $dT_c/dp \approx -1.3$ K/kbar, in line with previous low-p results [1,2]. At higher pressures T_c decreases less quickly. Indeed, incipient superconductivity – visible by a slight decrease of R towards lowest T – could be observed up to 11.7 kbar, the highest pressure where still metallic behavior was found (triangles in Fig. 1).

Up to this pressure we were able to detect SdH and AMRO signals. The SdH frequency F quickly increases by about 15% at $p = 6$ kbar from 199(1) T at ambient pressure. Qualitatively an increasing F is expected, caused by the decreasing unit-cell volume, i.e., increasing Brillouin zone under pressure. For a single-band metal F would be proportional to the 2D Brillouin-zone area resulting in only a 5% effect estimated from a typical compressibility of $\kappa_T \approx$ (100 kbar)$^{-1}$ for organic metals. In β''-$(ET)_2SF_5CH_2CF_2SO_3$, however, in addition to the closed orbit responsible for the SdH signal open bands are present [3]. Therefore – similar as observed for the α orbit in κ-$(ET)_2Cu(NCS)_2$ [4] – the area of the closed orbit may increase more rapidly when this change is compensated by the open bands.

In order to investigate the Fermi-surface topology of the closed orbit in β''-$(ET)_2SF_5CH_2CF_2SO_3$ in more detail we performed AMRO measurements for different pressures (Fig. 2). No change of the strongly elongated ellipsoidal orbit (axis ratio 1:9 [3]) can be found, i.e., the position of the AMRO maxima is almost pressure independent. The observed slight increase of k_F is in line with the increase in F. AMRO measurements at other azimuthal angles confirm the unchanged in-plane anisotropy of the 2D Fermi surface.

From the temperature dependence of the SdH signal the effective cyclotron mass m_c, and from the angular dependence the product gm_c, where g is the spin g factor, can be deduced. The pressure dependences of these band parameters are shown in Fig. 3, with g vs. p shown in the inset. At 10 kbar, $m_c \approx 1.23\ m_e$ is only slightly larger than the calculated bare band-structure mass of 1.07 m_e [3]. The strong decrease of m_c with p cannot be explained within an independent-electron picture, i.e., in first approximation the bare band-structure mass should remain constant under pressure. Therefore, this mass change mainly reflects the pressure dependence of many-body interactions. From our measurements it is, however, not possible to disentangle the different contributions of electron-electron and electron-phonon interactions. Interestingly, g increases by about 20% at 10 kbar. Since g is independent of electron-phonon interactions, our result shows the relevance of electronic correlations in β''-$(ET)_2SF_5CH_2CF_2SO_3$. However, electron-phonon interactions certainly cannot be neglected. Specific-heat data show that for the ET-based organic superconductors the coupling strength λ rapidly increases for materials with higher T_c [5]. It is therefore most plausible, that the pressure dependence of m_c is caused by a decreasing λ which in turn leads to the fast T_c reduction.

References

[1] S. Sadewasser, C. Looney, J.S. Schilling, J.A. Schlueter, J.M. Williams, P.G. Nixon, R.W. Winter, G.L. Gard, Solid State Commun. 104 (1997) 571.

[2] J. Müller, M. Lang, F. Steglich, J.A. Schlueter, A.M. Kini, U. Geiser, J. Mohtasham, R.W. Winter, G.L. Gard, T. Sasaki, N. Toyota, Phys. Rev. B 61 (2000) 11 739.

[3] J. Wosnitza, S. Wanka, J.S. Qualls, J.S. Brooks, C.H. Mielke, N. Harrison, J.A. Schlueter, J.M. Williams, P.G. Nixon, R.W. Winter, G.L. Gard, Synth. Metals 103 (1999) 2000.

[4] J. Caulfield, W. Lubczynski, F.L. Pratt, J. Singleton, D.Y.K. Ko, W. Hayes, M. Kurmoo, P. Day, J. Phys.: Condens. Matter 6 (1994) 2911.

[5] H. Elsinger, J. Wosnitza, S. Wanka, J. Hagel, D. Schweitzer, W. Strunz, Phys. Rev. Lett. 84 (2000) 6098.